Flood Risk Management Agent Based Modeling using ODD Protocol - Methodology

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1 Methodology

This part of the document is written by U.Suventhiran, Irusha Perera & Rashmi Pabodha.

Explain the "Overview, Design Concepts, and Details" (ODD) protocol [2].

1.1 Overview

1.1.1 Purpose

The model aims to simulate flood events, assess their impacts on a community, and evaluate the effectiveness of various flood risk management strategies. We know about Sri Lanka's 2024 flood disaster[1], which severely affected the southwestern regions of the country. Torrential rains led to widespread flooding, displacing thousands of residents, damaging infrastructure, and causing significant economic losses. By simulating such events, the model can provide insights into how different management strategies, such as early warning systems, evacuation plans, and structural defenses, can mitigate the damage and improve community resilience. The model will help identify the most effective measures to protect vulnerable populations, optimize resource allocation during emergencies, and guide long-term planning to reduce future flood risks[2].

In this model answers the following key points :

1. It examines what are the main factors trigger flood disasters and at what levels they occurs (give a brief idea for each factor condition's Impacts).
2. estimate the past & future losses if the flood disaster occurred in a location.
3. Helps to analyze flood disaster forecasts and precautions

1.1.2 Entities, State Variables, and Scales

In this model has 4 type of entities, those are residents - this is maintains randomly allocate as percentage of residents but we can implement a specific number or percentage. Second and third are infrastructure elements (e.g., buildings, roads) and natural elements (e.g., lakes, rivers, vegetation) these also set in percentage and this is help for our losses predictions impact of flood disasters. last one is emergency responders(Emergency responders, crucial in flood risk management, are modeled to simulate realistic responses, assess strategy effectiveness, and understand preparedness in mitigating flood impacts, ensuring safety, and saving lives. so they are help to minimize the losses and ext..) this is set as number of stations has that location. And Water level of rivers and lakes, Amount of precipitation, Near the ocean, Area with drainage system these are other state variables and we are take a location and set all impact factors levels and all things to observe in each conditions and study what happens in each situations.

Process Overview and Scheduling Key processes in this study include creating the environment and adding agents, fix any type of locations with any entities, state variables and scaling with a timesteps to observe how to spread flood and losses at the same time how to changing water levels in lakes and rivers and how to changing other factors and predict the losses, explain a flood any situation with our assumptions. and to state different type of conditions to create a location and observe all factors to state the forecasting flood disasters.

- **Time Steps**: Model runs in discrete time steps (e.g., short-run as hourly or days and long-run as months, years).
- **Processes**: Flood onset, agent responses, movement, interaction, and flood recession.

1.2 Design Concepts

1.2.1 Basic Principle, Emergence and Adaptive behavior

The basic principle of this study is to use an agent-based model to simulate flood risk management in river basins, exploring how flood risk emerges from interactions between agent-agent, agent-environment and also agent decision making(Figure 1).

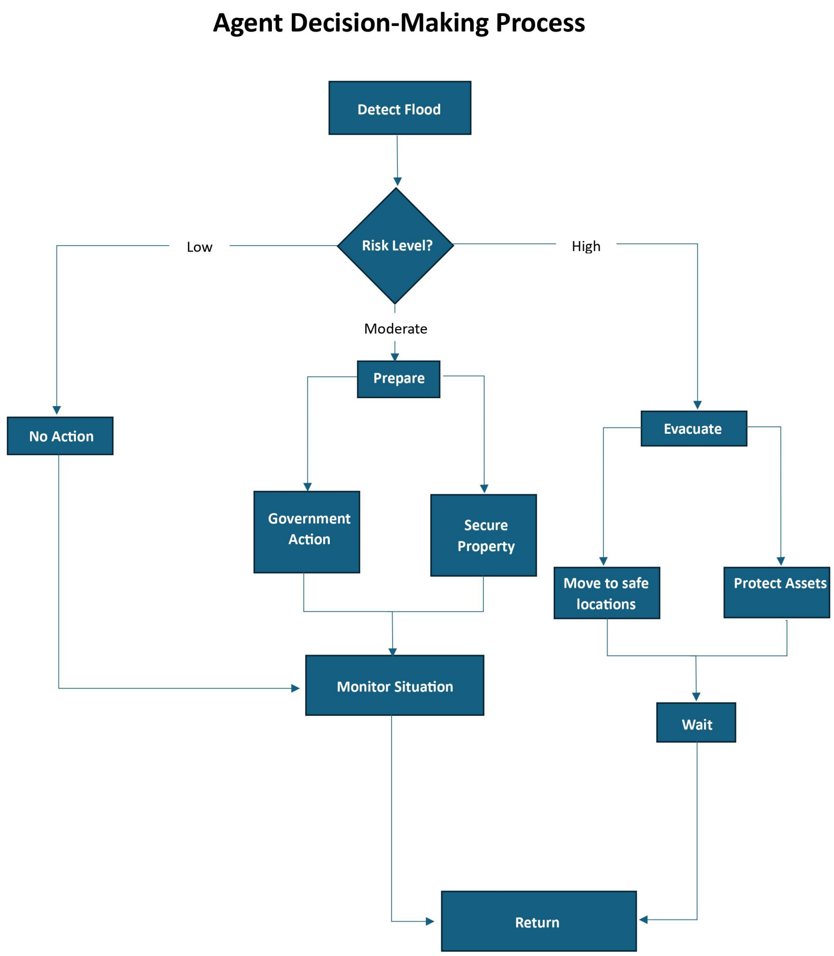


Figure 1: Decision-Making Process of residents and emergency responders during a flood event. This chart outline steps from detecting flood, assessing flood risk, actions of agents, and monitoring the situation until the flood reduces.

Figure 1 explain the decision making process of residents and emergency responders. This figure shows how agent make decision after detecting flood up until they return to their normal day. After detecting a flood, agents make different decisions based on the flood risk level which are low, moderate and high. If the flood risk is at a low level, agents tend to do nothing and instead they monitor the situation until the flood reduces while continuing their normal lives. If the flood level is moderate, agents prepare for different actions which are property securing and government action to reduce flood such as implementing flood control gates, drainage systems and barriers or floodgates will be opening/closing, if there are any floodgates. Then they will continue to monitor the situation until they can return to their normal life. If the flood level is high, then their decision becomes more critical. Evacuation process happens in this risk level. Residents will be evacuated to safe locations while protecting their valuable assets. Then they will wait in their current safe places until the water level decreases enough for them to return to their daily life. That explains the basic idea of how the agents make decisions depending on the flooding situation.

Human complex behavioral arise from the interactions of individual agents to flood risk such as people choosing same road for evacuation can lead to unexpected patterns of movements like heavy congestion on that road, due to the collective behaviors of each agent. Moreover, some areas might receive more assistance based on real time unexpected information resulting in unexpected patterns in how emergency services respond to a flood event. Not only the human agents, but environmental factors and infrastructure element together create unpredictable patterns, changing how water moves and sometimes making flooding worse in unexpected places. Therefore, understanding how these interactions create emergent patterns is more important in flooding situations. These kinds of emergence provide valuable insight to develop more effective and adaptive models to simulate flood risk and management[5].

Residents keep adapting their behaviors based on real time information that can be received from informal communication networks faster than the official channel, and real time flood conditions which might occur due to various emergent situations. For example, residents might decide to evacuate earlier or differently after receiving a flood warning based on their past experiences with floods. And also, emergency services might create new plans based on live information. So, exploring these adaptive behaviors helps to develop a more flexible and responsive flood risk management system[3].

1.2.2 Objectives, Prediction and learning

The main objective of this study is to understand and improve flood risk management in river basins by using an agent-based model.
To understand and improve flood risk management, this study aims to develop a flexible and effective Agent Based model including user friendly graphical user interface by observing and analyzing interaction between individual agents that influence flood risk including emergence and adaptive behaviors.
Furthermore, the model will help to identify the most effective ways to protect communities and will provide long term planning to reduce future flood risk.
Finally, this study aims to provide valuable insights into difference management strategies such as early warning systems, structural defenses, policy making and resource allocation by testing under various scenarios. And also, these insights will provide valuable information for different fields like urban planning etc.

This model can predict how various factors that influence flood risk affect risk management under different scenarios. Therefore, one of the predictions will be identifying the most congested evacuation routes during evacuation process using agent interactions, including emergence and real time information. Furthermore, the model will be able to estimate evacuation time and response time of emergency services under different situations, providing crucial information for risk time management and for better resource allocation and response planning[5].

Additionally, this model will be able to adapt and improve its predictions based on new data such as adaptive behaviors of residence based on past experience and learning of residence and emergence as explained in section 1.2.1[5].

1.2.3 Sensing

To improve accuracy of the model, data from various formal and informal sources will be used and adapted into this model. Mainly the model will gather data such as whether conditions, river flow rates and flood level etc. in a formal way. Furthermore, this model incorporates informal data like the past experience of resident into the model, which helps to define effective rules on agent behaviors and improve its predictions.[5].

1.2.4 Interaction

In the flood risk management agent-based model, much of the understanding and mitigation of flood impacts lie in how well such diverse entities can interface with each other. Residents interact with their physical space as they respond to warnings issued for a flood event by making decisions about whether to evacuate and by what routes. Such decisions may then bring about emergent behaviors that complicate issues at hand, such as timely evacuation and great risks, due to traffic congestion on major evacuation routes. Emergency responders interact with the resident population on matters of assistance, and advice regarding evacuation, and rescue operations. Their effectiveness depends on real-time communication and coordination between them and the residents they are assisting.

This also includes the interaction of the floodwaters with infrastructure elements such as buildings and roads, relating to the extent of physical damage and economic losses. Other natural factors are the rivers and vegetation, which normally interact with the floodwaters to affect the spread and intensity of the floods. In this way, the model picks up these complex interactions to simulate how strategies for improved communication systems, better infrastructure planning, and efficient infrastructure in terms of emergency response protocols can be tuned for enhanced community resilience and reduced adverse effects of floods. Figure 2

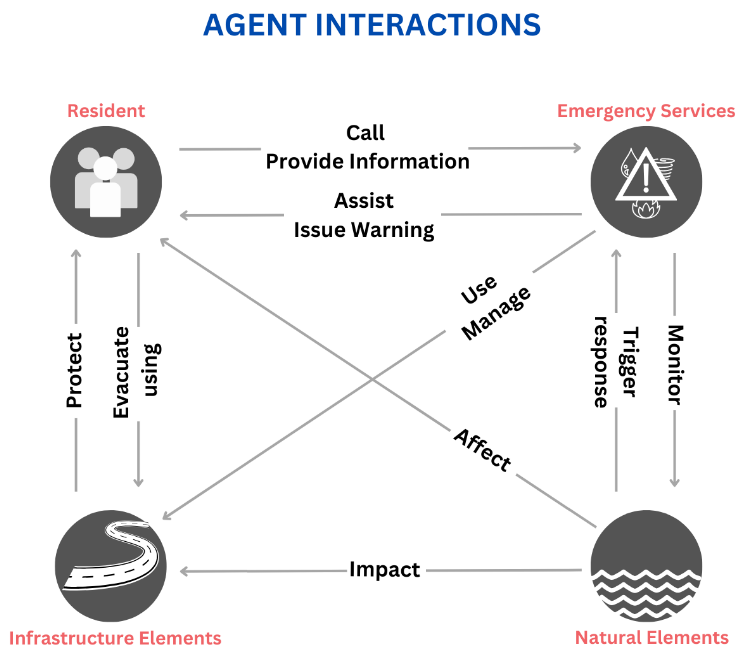


Figure 2: Agent Interactions: Basic interactions among residents, emergency services, infrastructure elements and natural elements

Above Figure 2 shows basic interaction between each agents which considered in this model Emergency services issue warning about floods which triggers response by natural elements like river to residents and assist them during the flood by securing properties and rescuing by using infrastructure element lie road and buildings while managing them. And residents call emergency services requesting help, assist or to give current information about flood. Then residents evacuate using infrastructure elements such as roads, buildings, etc. On the other hand, infrastructure elements protects residents. And also, natural elements like rivers and lakes affect residents and impact infrastructure elements.

1.2.5 Stochasticity

Randomness and variability, or stochasticity, constitute a very important component of this flood risk management agent-based model. One of these aspects concerns modelling real-world uncertainties. For example, we randomize the initial distribution of residents in the modelled area to understand the variability in population density and settlement patterns. We further stochastically generate the extent and intensity of flood events based on historical data and weather pattern trends, making a model setup that simulates a large space of probable flood scenarios. In resident evacuation behaviour, stochasticity infiltrates into their decision-making and movement patterns to capture individual differences and unpredictability of human actions. Moreover, it is also possible to randomize the deployment and efficiency of emergency responders to simulate potential logistical challenges or actual decisions taken in real-time situations. In this way, this stochasticity will enable the model to run through several scenarios to give a solid analysis of the flood risk management strategies under varying conditions, thereby offering an understanding of possible impacts and mitigation measures in their entirety.

1.2.6 Collectives and observation

In the flood risk management agent-based model, collectives are representations of groupings of agents that act together or exhibit some other kind of collective behaviour in the case of flood events. For example, evacuation of residents often takes place in groups—families or community clusters—that engender collective movement patterns and hence cause road congestion or bear on the success of evacuation plans. Emergency responders will also operate in teams, coordinating their efforts to rescue people, provide medical aid, and manage shelters. Such collective actions are important in ensuring efficient and effective response to flood events. Furthermore, community organizations and local governments also act as collectives in carrying out flood preparedness measures, disseminating information, and facilitating recovery efforts. Simulation is capable of modelling such collective behaviours to evaluate the benefits and challenges of coordinated actions, pinpointing possible bottlenecks and proposing improvements in strategies for collective response to improve overall flood resilience.

For any flood risk management agent-based model, observation is also a very important component, where by variables and results of the simulation can be monitored and analyzed. Observed key variables include, among others, the number of residents evacuated to safety, the extent of infrastructure damage and intensity of the damage, the efficiency and effectiveness of emergency measures taken, and the economic impact of the flood event. The changing water level, precipitation rate, and floodwater movement over the landscape are recorded by the model. The activities of residents and responders map not only the behaviours and interactions but also understand the patterns and emergent phenomena. From this type of observation, very useful data relating to the testing of the different flood management strategies, known weaknesses of plans, and proposing improvements can be gathered. The model, through the observation and analysis of such variables in a systematic way, can shed light on the dynamics of flood events and different mitigation measures that may have an impact on response measures, hence leading to effective decision-making in flood risk management.

1.3 Details

1.3.1 Initialization

This model starts off with a location that is specified for its entities, state variables, and scales. This can be implemented as a roughly $5 \times 5\,\text{km}^2$ area, and a baseline flood scenario (this is other rain falling, water levels of lakes and rivers, near the ocean or not, and area with drainage system or not). For example, set residents as a percentage of residents, infrastructure elements (e.g., buildings, roads), and natural elements (e.g., lakes, rivers, vegetation). Some entities are set as percentage and others as number of lakes likewise and emergency responders also set number of stations to get the model going.

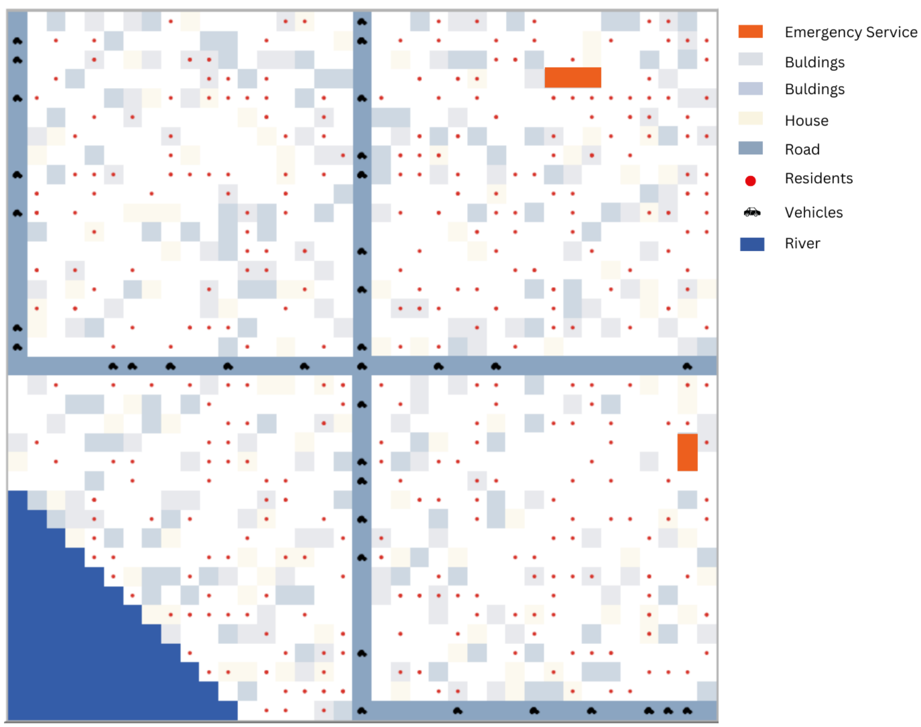


Figure 3: Virtual City in our model, including river as natural element, roads and building (blue blocks) as infrastructure elements, residents (red dot) and emergency services (red blocks)

1.3.2 Input Data

If we first implement the $5 \times 5\,\text{km}^2$ area using historical flood data, topographic maps, and demographic data then that area fixed and no other input data.

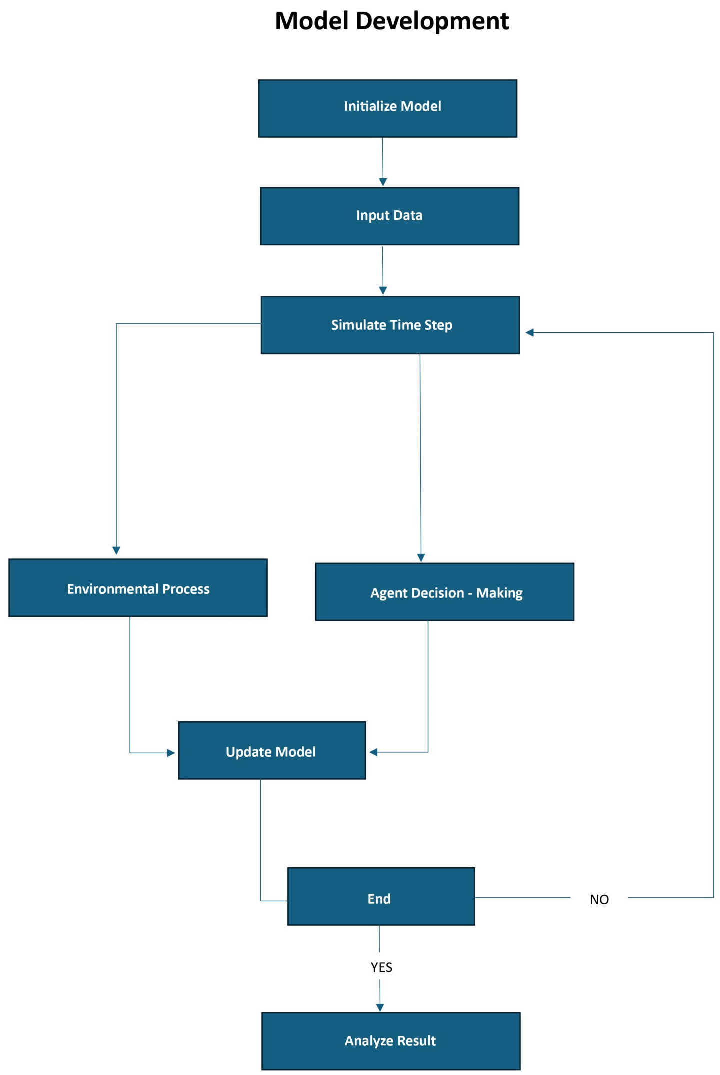


Figure 4: High-Level view of the model

The above Figure 4 shows high level view of the main components and process of the model development. Model starts by setting up its initial state. It involves creating the environment. initializing agents (river, buildings, residents, agents, emergency services) and setting parameter values. Then by inputting data such as external data (historical rainfall data, topographical information), the model is being developed. Next step is simulating time step(days). This represents a unit time in the simulations. It is the beginning of the loop and runs several times according to initialized simulations run time. This loop includes environmental processes such as simulating rainfall and water flow in the river system, etc. and agents' decision-making process such as resident decisions and government decisions. Then after based on above two processes the current state of the model will be updated including agents' statuses, environmental changes. Then the model checks whether the simulation will end or not. If the model ends, then it will analyze the results and display the results. If not, the model will continue to the next day.

1.3.3 Submodels

Here, we define the following three sub-models:

1. Forecasting the flood disaster model

   Initially, we establish the ideal flood disaster conditions and forecast when those criteria would be met to provide information to emergency responders and entities (residents).

2. Determine the flood losses model

   We will calculate the extent of the damages to those entities by starting the model, first we determine roughly $5 \times 5\,\text{km}^2$ area and divide $100 \times 100\,\text{m}^2$ sub-areas and observing the flood distributions, seeing the flood spreading, and observing the water levels to display a plot what is the water level of each sub-areas. And we are develop a model from the [4] article methodology. below the image show that image show sample methodology.

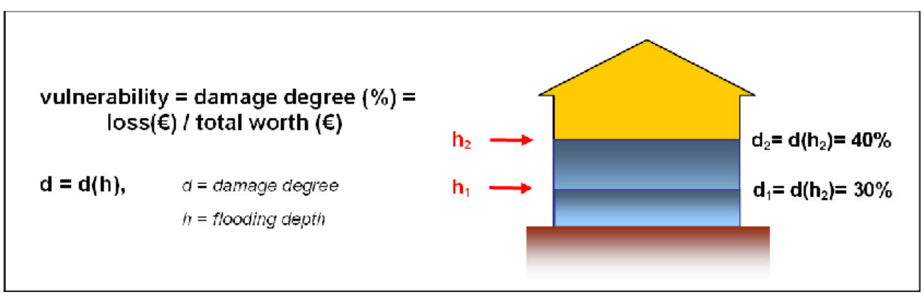
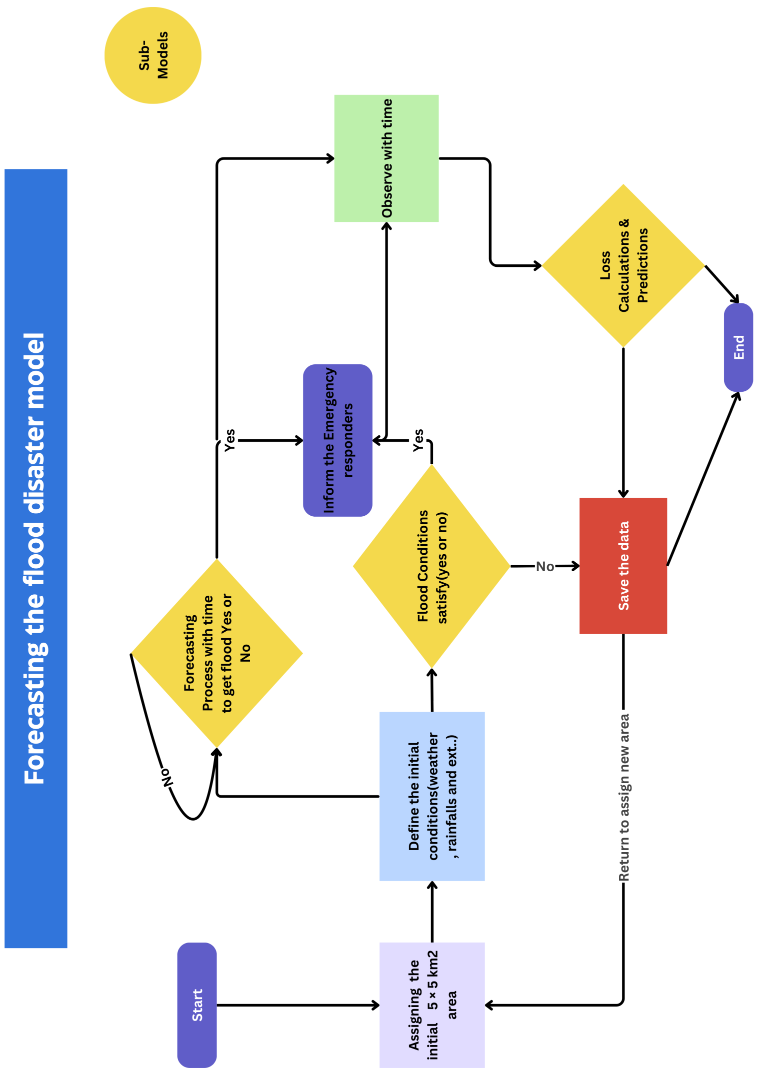


Figure 5: damage analysis of our sub-models - get in article([4])

3. Setup the emergency responder

   Establish first the parameters that will allow emergency responders to react, save lives, and reduce damage to local entities. And below the flow chart show how to works this sub-model and relationship of other sub-models.

Figure 6: Flow chart of our sub-models: I this flow chart represents what are the sub-models in this model, our model what can do and how to works and overview of our flood model.



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A Individual Contributions

1. U. Suventhiran: Overview in Section 1.1, Details in Section 1.3, Fig 5: damage analysis of our sub-model and Fig 6: Flow chart of our sub-models.
2. Rashmi Pabodha: Basic Principle, Emergence and Adaptive behavior in Section 1.2, Objectives, Prediction and learning, Sensing and Figure 1: Agent Decision-Making Process, Figure 2: Agent Interactions.
3. Irusha Perera: Interaction, Stochasticity, Collectives and observation in Section 1.2 and Figure 3: Virtual City, Figure 4: High-Level view of the model.